Editorial

Late Cenozoic fluvial history worldwide: a context for the Yellow River record

The impetus for this special issue came from a combined discussion and field meeting convened in September 2017 in Lanzhou, China, under the combined auspices of the Fluvial Archives Group (FLAG), the National Natural Science Foundation of China (grant nos 41571003, 41730637, 41871001 and 41971005), the Second Tibetan Plateau Scientific Expedition and Research Program (STEP), Grant No. 2019QZKK0205, Project 111 (BP2018001), based in Lanzhou, the Geologists' Association and the Quaternary Research Association (the last two based in London). The meeting included a field excursion that visited localities in the Yellow River (Huang He) catchment between the GongHe Basin, on the NE flank of the Tibetan Plateau, and Jintai, at the downstream end of the Lanzhou Basin, also including the tributary Huangshui valley and the endorheic Lake Qinghai basin. The overarching themes for the meeting, and for the special issue, concern the evolution of the Yellow River in an area of strong neotectonic activity, and comparison of what is clearly an exceptional fluvial system with others in the region and more widely. The course of this, China's second longest river, is far from straightforward, crossing numerous geological structures and taking a notably indirect route to the ocean. It can be shown that the river, in its complete modern form, arose relatively recently, with its upper and middle catchments having previously been a series of separate internally draining basins. It has also been argued, however, that the Huang He was formed in the Eocene as an eastward-draining river and that it developed its characteristic rectangular course around the Ordos Block (downstream of the Lanzhou Basin) in the late Miocene to early Pliocene (e.g. Lin et al., 2001).

There are significant offsets in the course of the Yellow River where it crosses major strike-slip faults (e.g. Perrineau et al., 2011), showing (unsurprisingly) the influence of active tectonism on its evolution. Indeed, the plate-tectonic collision between the Indian subcontinent and the Eurasian continent, which resulted in the formation of the Tibetan Plateau (e.g., Molnar et al., 1993), is fundamental for understanding the origin and evolution of this river system. Continued convergence of the two plates also accounts for eastward propagating extrusion of the plateau during the Late Cenozoic–Quaternary, giving rise to extensional tectonic activity, rifting, and related uplifted blocks (Molnar & Tapponnier, 1975; Peltzer &

Tapponnier, 1988; Li et al., 2001; Zhang et al., 2003; Hintersberger et al., 2010; Liu et al., 2013). Thus were formed the various fault-bounded and largely infilled basins through which the Upper and Middle Yellow River now flows, having cut gorges through the intervening up-faulted older rocks. In its upstream reaches the Yellow River flows across several significant sedimentary basins, including the Zoige, Xinghai–Tongde, GongHe, GuiDe, Xunhua, and Linxia basins, separated by uplifting mountain ranges: the Anyemaqen Shan, Heka Nan Shan, Waligong Shan, Zamazari Shan and Jishi Shan (see Perrineau et al., 2011). The 'basin and range' composition of the Tibetan Plateau is central to understanding its generation and progressive growth, with this structure established early on the orogeny and the building of the massif north-eastwards by repeated formation of thrusted narrow mountain belts, with elongate basins between them (Tapponnier et al., 2001; see this issue, Hu Xiaofei et al., 2019; Wang et al., 2019); thus both the ranges and the basin fills are potentially younger in the NE part of the plateau, including the area drained by the Yellow River.

An unanswered question is the extent to which the characteristics of the Yellow River system are the product of its unusual tectonic setting. Endorheic basins are not unique to orogenic regions and were evidently more common in pre-Quaternary times (see Bridgland et al., 2020), so contributions addressing systems in which basins occur or have occurred in the recent geological past (e.g., in this issue, Cunha et al., 2019; Gouveia et al., 2020) provide a valuable comparison within a compendium that will summarize the latest thinking on the evolution of the Yellow River, of other rivers in China and comparator systems in other parts of the world. In so doing it will explore not just basin-inversion and drainage system evolution but also fluvial incision and river terrace formation and the relation of river systems to climatic variation and sea-level change.

Contents of the special issue

In the first of several papers on Chinese fluvial archives and the evidence they provide on the Yellow River and the formation of the Tibetan Plateau, Zhenbo Hu et al. (2019) report on studies of gravel deposits, in particular using heavy-mineral analyses, that have thrown light on the earliest occupation by the Yellow River of the Sanmen Gorge, through which its headwater drainage from the Tibetan Plateau gains access to its lower catchment on the North China Plain, leading to its outlet into the Pacific Ocean. They recognize a high-level gravel, which lies on a planation surface preserved above the flanks of the gorge and has a composition markedly different from the terrace deposits of the Yellow River. Material from the upper Yellow River catchment is lacking in this high-level gravel, which is attributed to a small local river system that developed during the period of planation, before the formation of the Sanmen Gorge. Comparative analyses were also undertaken of basin-fill deposits from the fluvio-lacustrine system (the Sanmen palaeo-lake) that formerly occupied the Fenwei Basin, upstream from the gorge, and was captured and drained by the Yellow River as a result of gorge formation, causing 'basin inversion'. These basin-fill deposits also reflect more localized derivation, as indicated by a relative abundance of quantities of unstable hornblende. This was one of many endorheic basins that formerly existed along the course of the Yellow River, as noted above. The work by Hu et al. has confirmed a minimum age of ~1.2 Ma for the formation of the Sanmen Gorge.

Moving to the north-western margin of the Tibetan Plateau, Wang et al. (2019) have used the pattern of spatial variation in fluvial channel-steepness indices as evidence for differential rock uplift in the eastern Altun Shan, an active orogenic belt. Improved knowledge of uplift and related features in this area promises to enhance understanding of the uplift of the Tibetan Plateau as a whole. The basis for this work is the relation between Channel Steepness Index (Ksn) and fluvial incision, from which bedrock uplift, as a measure of regional tectonic activity and intensity, can be estimated. Using the Digital Elevation Model 'ASTER GDEM', in combination with ArcGIS and MATLAB software, the authors extracted Ksn indices that imply a progressive increase in uplift from west to east along the eastern Altun Shan range, with strike-slip movement dominating in the west and thrust faulting in the east. The work also points to higher uplift in the northern part of the mountain belt. These results, which can be linked with "the imbricated thrusting transformation-limited extrusion model" of the Tibetan Plateau, are in keeping with previous findings on the activity of the eastern Altyn Tagh Fault. The work underlines the value of fluvial archives in studies of landscape evolution and tectonic activity.

In a somewhat similar study, Xiaofei Hu et al. (2019) have also used evidence from river terraces as a measure of tectonic activity, this time in the Yumu Shan, a relatively small and recently uplifted mountain range in the Hexi Corridor basin, NE Tibetan Plateau. In this work, deformed terrace surfaces were measured across the North Yumu Shan Fault and a related fold, from which the kinematics of faulting and folding were determined. The results suggest that folding above the slipping fault is the main deformation process in accommodating crustal shortening hereabouts, even where the thrusting has broken the surface. The authors suggest a fault slip rate 2–3 times higher than previous estimates, with the implication that the onset of uplift of the Yumu Shan range (and perhaps, thereore, of the northernmost edge of the Tibetain Plateau) is more recent than hitherto envisaged.

In a third study using river-terrace data to assess tectonic activity, Wu et al. (2019) report on the spatial variation of incision rates in the Tian Shan range, an active orogenic belt to the north of the Tarim Basin, north of the Tibetan Plateau. Their work seeks to tease apart the contributions of tectonic activity, climate, and surface processes in the Tian Shan, based on both remote and field-based observations from which terrace sequences were defined in four valleys in the frontal region of this mountain range, belonging (from west to east) to the rivers Kuitun, Jingou, Manas and Urumqi. For each of these rivers, a single 'reference terrace' was selected, these being T5 (Terrace No. 5) in the first three and T4 of the Urumqi. The reference terraces were used to reconstruct the palaeo-geomorphology prior to floodplain abandonment during fluvial incision and resultant terrace formation. Comparison of the present-day and the reconstructed (pre-incision) topography allowed the volume of eroded material and thus the depth of incision to be estimated, averaged across the erosion area. In combination with the age of each reference terrace, this allowed fluvial incision rates to be estimated, these showing a notable decrease from west to east, from ~5.1 mm/yr in the Kuitun to ~0.9 mm/yr in the Urumqi, a pattern that is in good agreement with changes in slope, relief and N–S crustal shortening across the range. These findings have led the authors to propose that tectonic activity has been the primary influence on erosion and landscape evolution in the Tian Shan.

The study area for the work described in the next paper is the SE extremity of the Tibetan Plateau; by Zhang et al. (2019), it concerns Middle–Upper Miocene sediments filling the Xiaolongtan Basin, which have yielded a richness of ancient hominoid fossils as well as a record of the uplift of the SE Tibetan Plateau and of the evolution of the Indian monsoon. Hitherto lacking a precise chronology, these sediments can be better constrained as a result of the research presented in this paper: high-resolution palaeomagnetic dating of the 487.5 m-thick fluvio-lacustrine sequence of the Xiaolongtan Basin. Eleven reversed and normal zones were revealed, spanning magnetostratigraphical ages of ~14.1–10.0 Ma for the full sequence, with the two hominoid fossil beds dated at 12.5 and 11.7 Ma. Lithological and palaeo-ecological studies have allowed the recognition of different palaeo-environmental phases of considerable importance in the reconstruction of climatic evolution in the wider region. Phase I, following the formation of the basin (14.1–12.6 Ma), was characterized by warm and humid forest–steppe conditions, Phase II (12.6–11.6 Ma) by subtropical evergreen broad-leaved forest, Phase Ⅲ (11.6–10.0 Ma) by warm and dry conditions, with lake shallowing and evaporation, and finally Phase Ⅳ (after 10.0 Ma) was marked by a subtropical semi-arid steppe environment. Deposition largely ceased after ~10.0 Ma, albeit recurring sporadically until the Early Pleistocene.

Returning to fluvial terraces, Xun Yang et al. (2019) report on data from the Hanjiang River in the Hanzhong basin, to the south of the Qinling Mountains. These mountains separate that basin from the valley of the Weihe, an important right-bank tributary of the Yellow River, which flows into the Fenwei Basin and joins the Yellow River just upstream of the Sanmen Gorge, the formation of which was discussed in the first paper (Zhenbo Hu et al., 2019). This study region coincides with the climatic boundary between the temperate north and subtropical south of China and is the location of numerous important Palaeolithic archaeological sites on river terraces, abundant artefacts having been excavated from silts overlying fluvial gravels and coarse sands. The authors report on detailed sedimentological studies, notably grain-size and grain-shape analyses, supported by end-member modelling, from which they have reinterpreted some of the sedimentary contexts as fluvial (floodplain and channel) rather than aeolian deposits, as was hitherto supposed. Aeolian capping sediments are present, but there is a gradual transition, with no evidence for a considerable hiatus, between the fluvial and wind-blown deposits, lithic artefacts being represented in both depositional environments. This important interpretation shows that the timing of hominin occupation coincides with the ages of the river terraces.

The next paper, by Huai Su et al. (2019), considers the origins of a headwater drainage arm of the Yangtze system: the Jinsha River, regarded by many to have once been a tributary of the southward-draining Palaeo-Red River and thus flowing into the South China Sea prior to capture by the Upper Yangtze (e.g., Barbour, 1935; Clark et al., 2004). Evidence for this drainage reorganization includes the sudden cessation, at ~5.5 Ma, of sedimentation in the Red River submarine fan (Wang et al., 2011), which had been fed by the larger Palaeo-Red River system. There has, however, been little geomorphological evidence cited in support of a capture event of that age. Addressing this problem, the authors have studied the terrace system of the Middle Jinsha and attempted to establish a chronological framework using electron spin resonance, cosmogenic nuclide ($^{26}Al/^{10}Be$) and optically stimulated luminescence (OSL) dating. Their data provide ages for nine Jinsha terraces, ranging from 1.07 (T9) to 0.047 (T1) Ma, and pointing to an average fluvial incision rate over that interval of ~147 mm/ka. Extrapolation of this incision rate in relation to the palaeo-topography and to digital elevation model data for the filling of the deeply incised Jinsha valley (which suggests that the present drainage system was established after the disruption of a palaeo-landscape surface at an elevation of ~2000 m above sea level) gives an approximate age for the formation of Middle Jinsha River drainage of 5.5 Ma. Thus there is excellent agreement with the previously estimated date for cessation of sedimentation in the Red River submarine fan.

Remaining in the Yangtze system, the next paper is by Yantian Xu et al. (2019), who review the role of sea-level change in lake formation on the floodplains of the middle and lower reaches of that river. Indeed, this region, the Yangtze Plain, is characterized by numerous lakes, including the three largest bodies of freshwater in China: Lakes Poyang, Dongting and Taihu. There is no agreed explanation for lake formation hereabouts, with tectonic activity and climatic, sea-level and anthropogenic influences amongst the potential factors. The authors provide a review of published sedimentary and chronological records from the three above-named lakes, from which they propose that sea-level change has been a principal influence on their formation. Key evidence comes from the recognition of a landscape of incised valleys and interfluves that prevailed throughout the Yangtze Plain during the last glacial maximum, at a time when global sea level was >120 m lower than present and there was no large lake on the plain. The lakes that now characterize the region were first established in the Holocene, when the incised valleys were infilled. The authors suggest that similar climate- and sea-level-controlled lake-forming processes would have operated during earlier glacial–interglacial cycles, both here and in other eastern coastal Chinese rivers. This sea-level forcing hypothesis suggests a greater influence of sea-level change on the Yangtze Plain, remote from the river mouth, than hitherto envisaged, as well as closer linkages between Earth-surface processes and glacial–interglacial cycles.

A single contribution to the special issue represents the western side of the Himalayan Plateau; by the Indian team of Poonan Chahal and co-workers, it concerns the Late Pleistocene fluvial activity of the Zanskar River, part of the Upper Indus system, NW Himalayas. The Zanskar flows northwards from the Higher Himalayan upland, where the Indian summer monsoon is dominant, through the folded and thrusted Zanskar ranges in Ladakh, an arid, westerlies-dominated region. Its valley can be divided into upper and lower divisions, both with substantial sedimentary archives, separated by a gorge nearly 60 km in length. From the combined study of the sediment fills, morphostratigraphy, OSL dating and provenance analysis (based on U–Pb Zircon chronology), the authors recognize three phases of aggradation in the Zanskar valley, during (1) the cool, wet MIS 3 episode (~43 to ~32 ka), (2) the transition from the dry LGM to the wet early Holocene (20–12 ka) and (3) the early–mid Holocene (9–6 ka), when the monsoon was strengthened. The Padam basin, where the confluence of the rivers Doda and Tsarap Lingti Chu gives rise to the Zanskar, is recognized as important for sediment storage, especially during the oldest aggradation phase, when it contained ~3.25 km^3 of sediment, more than three times the present volume. Chahal et al.'s provenance analyses suggest that, notwithstanding a very low gradient and separation by the deep narrow gorge reach, the upper and lower Zanskar catchments remained connected throughout their aggradational history, with material from headward erosion in the upper reaches dominating the valley fills. This is in contrast to the more humid southern part of the Himalayas, where sediment provenance reflects catchment-wide erosion.

There follows a group of papers that provide comparative data from other regions in which sedimentary basins have played an important role in the Late Cenozoic. The first of these, by Cunha et al. (2019), concerns the inversion of the Douro Cenozoic Basin and the associated transition from an endorheic depocentre in central Iberia to exorheic westward drainage to the Atlantic Ocean: the initiation of the River Douro. There are clear parallels here with the evolution of the NE Tibetan Plateau basins, although the high altitude of the latter is an important difference. A similarity is the long-standing uncertainty as to the relative roles of basin overspill as opposed to headward erosion and river capture. Investigation by the authors of the Portuguese sector of the Douro catchment has thrown new light on this issue, however. Flowing from the weakly resistant sedimentary infill of the Cenozoic Basin, the modern Douro reaches the Atlantic after passing through durable granitic and metamorphic rocks. The older endorheic drainage is recorded by Cenozoic sediments and a planation surface that, although displaced by faults, is typically at 500 to 1000 m above sea level (a.s.l.), constituting the Mountains and Plateaux of Northern Portugal. Inset into the planation surface is a broad fluvial surface at 650–600 m a.s.l., which represents a large ENE–WSW depression, thought to record the initiation of drainage re-organization towards the Atlantic. A lower inset surface, 500–450 m a.s.l., records the first unequivocal exorheic ancestral Douro valley. At lower levels is the terrace sequence of the Douro, from Terrace 9 (T9), 246–242 m above the modern riverbed, to T1, 13–17m above modern Douro. OSL dating has been used to constrain the three lowest terraces, indicating that they represent parts of the last three Milankovitch climatic cycles. Extrapolation of the implied incision rate leads Cunha et al. to suggest a probable timing for the drainage re-organization at ~3.7 to 1.8 Ma. The narrow and entrenched lower part of the Douro valley records subsequent enhanced fluvial incision by the Atlantic drainage, related to continuous regional crustal uplift, cooler climates and associated lower sea level.

The next paper, by Gouveia et al. (2020), concerns the Iberian Mondego and Lower Tejo (Tagus) Cenozoic basins, to the south-west of the Douro/Duero (Cenozoic) basin. Occupying much of SW Iberia, these were neighbouring depocentre basins that had exorheic drainage to the Atlantic during most of the Cenozoic (Cunha, 2019), drained by precursors of two of the peninsula's west-flowing rivers, the Tajo/Tejo/Tagus and the Mondego (Cunha, 2019; Demir et al., 2018). The authors have turned their attention to dating the culminative sedimentary unit of the Lower Tejo and Modego basin-fills, which represents the final accumulation phase before inversion occurred and the drainage systems began to cut substantial valleys in the weakly resistant Cenozoic infill deposits and, where it was encountered, narrower valleys in the much harder pre-Cenozoic basement. Indeed, this allostratigraphical unit, designated UBS13, is thought to record the re-establishment of Atlantic drainage in both basins following a period of endorheism during the late Tortonian–Zanclean (~9.6 to 3.7 Ma). It can thus be seen as a combined high-level precursor and/or uppermost element of the well-developed terraces that record the subsequent incision of the present valley systems (e.g., Ramos et al., 2012; Cunha et al., 2017), representing a succession of events comparable with the Yellow River basins, although with different timing (see other contributions to the special issue, including the next paper, the summary by Bridgland et al., (2020)). In an attempt to address the dearth of geochronological data on the timing of basin inversion, Gouveia et al. have used the ESR method to date unit UBS13 in these Portuguese basins. They obtained reliable dates from the Al-centre, but ESR data obtained using the Ti–Li centre have clearly underestimated the true burial ages, particularly with reference to pre-existing biostratigraphical dating of the Vale Farpado site (3.7–3.6 Ma) for basal UBS13 sediments (Cachão, 1990). ESR (Al-centre) ages of 3.0 to 2.3 Ma were obtained by Gouveia et al. for the mid-UBS13 deposits, whereas the uppermost part of the unit produced a probable age of ~1.8 Ma. These results are of considerable significance as the first numerical ages obtained for the uppermost Cenozoic basin-fill sediments of western

Iberia, providing a maximum age bound for the subsequent fluvial incision by the Atlantic rivers.

The last of the group of papers considering the occurrence of sedimentary basins and their contributions to Cenozoic fluvial archives and changes in relation to landscape and drainage basins is by Bridgland et al. (2020). This is a review and synthesis that interrogates the geographical distribution of sedimentary basins, both endorheic and exorheic, as well as their differing pattern of occurrence during recent geological time. There is a particular emphasis on comparison with the basins of the Yellow River on the Tibetan Plateau, given the location of the meeting from which the special issue arises. The authors propose that endorheic subsiding basins were more common in the pre-Quaternary, with many such basins that existed during the earlier Cenozoic having inverted, as well as having been 'captured' by exorheic drainage. Such changes can be seen in the relatively recent history of the Yellow River, with further captures and inversions likely in the near future. The extent to which these high-level basins, brought into existence by the orogenesis that formed the Tibetan Plateau, are comparable with others occurring in areas of lower altitude and relief is one of the issues explored. Comparative systems from many areas are invoked, for example in the Mediterranean region, where there are numerous erstwhile depocentre basins, which accumulated stacked sedimentary sequences in pre-Quaternary times and were typically captured and inverted in the late Pliocene or at around the Pliocene–Pleistocene boundary, a timing suggestive of correlation with climatic cooling. Other basins inverted later, at around the time of the mid-Pleistocene Revolution, perhaps coinciding with the increased climatic severity associated with the change to 100 ka Milankovich cycles at that time. Links with isostasy (sedimentary/erosional) and with crustal type are also explored.

The special issue is completed by a pair of disparate contributions covering other aspects of research into fluvial archives, all of them of potential applicability to the Yellow River and other systems. The first of these, and the penultimate paper in the special issue, reports on novel methodology. By Peng et al. (2019), it outlines a method for palaeoflood reconstruction and flooding phase identification, as applied to the River Meuse (Maas) in the Netherlands. Peng et al. have investigated the evolution of the Holocene floodplain of the lower reaches of this major European river, including its flooding phases, studying channel-fill and floodplain deposits in sediment cores and using the grain-size distribution therein. They have constructed a Flood Energy Index (FEI), combining end-member modelling results with laboratory observations and allowing identification, from the grain-size signal, of phases of past increased flooding. They emphasize the importance of considering the quality of grain-size datasets before their use in the reconstruction of flood events, given the common occurrence of concretions and organic-rich inclusions that would compromise the data. The temporal variation of FEI in the Meuse sediments points to a record of multi-centennial flood phases occurring at intervals of ~500 to 1000 years during the early–middle Holocene. They also recognize a period of low flood occurrence coinciding with the Subboreal, which is attributed to a cooler and dryer episode after the Holocene Climatic Optimum. The first flooding phase in the late Holocene, at ~2800 cal BP, is correlated with the 2.8 ka climate anomaly, while more recent flood maxima are thought to coincide with the Roman Period, the Medieval Warm Period and the Little Ice Age, with clear indications that humans have had a considerable impact on the fluvial dynamics in the Meuse. This valuable study therefore combines a detailed Holocene fluvial archive, as found in many regions globally, with methodological innovation.

The final paper is the only one to report on a study from outside Eurasia. By Willem Viveen et al. (2019), it concerns Holocene river systems in the Peruvian Andes, data from which reveal centennial-scale variations in the South American Summer Monsoon (SASM) and in base-level fall. Previously established from paleoclimatological records such as speleothems (Kanner et al., 2013; Bustamente et al., 2016) and lacustrine sequences (Vuille et al., 2012; Stansell et al., 2013; Baker and Fritz, 2015), the effects of changes in the SASM in the Peruvian Andes have been little researched hitherto. Viveen et al. use sedimentological, stratigraphical and geomorphological evidence, constrained with OSL and radiocarbon dates, to show that rivers draining from the Peruvian Andes have responded to such changes. Fluvial terrace profiles show that the River Mantaro and its tributary, the Cunas, incised and laid down sediments simultaneously as a response to changes in regional base level and increased SASM activity at 4418 ± 500 years ago. Between 2245 ± 217 years ago and the present, SASM events significantly increased in frequency, having been at a low level for much of the Holocene. The majority of terraces in both rivers were formed during this recent period of enhanced monsoon activity, at intervals of ~250–300 years between ~2245 and 1200 years ago and of ~150 years during the last ~850 years. Episodes of sedimentation can be correlated with periods of increased precipitation and glacier retreat in the Peruvian Andes, whereas incision, amounting to 34 m since 4418 ± 500 years ago, is attributed to adjustment to base-level fall. Viveen et al. consider that other rivers in the Peruvian Andes have shown a similar response to centennial-scale variations in SASM activity; they conclude that such variations in the monsoon are a major driver of fluvial activity, rather than variations in El Niño Southern Oscillation, as commonly supposed previously.

Acknowledgements

The Lanzhou meeting and this resulting special issue was supported by the Second Tibetan Plateau Scientific Expedition and Research Program (STEP), Grant No. 2019QZKK0205, by the National Natural Science Foundation of China (Grant nos 41571003, 41730637, 41871001 and 41971005) and by Project 111 (BP2018001).

The Quaternary Research Association provided a meeting grant and published the field guide (Hu et al., 2017).

References:

Baker, P.A., Fritz, S.C., 2015. Nature and causes of Quaternary climate variation of tropical South America. Quat. Sci. Rev. 124, 31–47.

Barbour, B.G., 1935. Physiographic history of the Yangtze. The Geographical Journal 87, 17–32.

Bridgland, D.R., Westaway, R., Hu, Z., 2020. Basin inversion: a worldwide Late Cenozoic phenomenon. Global and Planetary Change [this issue, in press]

Bustamante, M.G., Cruz, F.W., Siffedine, A., Cheng, H., Apaéstegui, J., Vuille, M., Strikis, N., Moquet, J.S., Novello, V.F., Guyot, J., Edwards, L., 2016. Holocene changes in monsoon precipitation in the Andes of NE Peru based on $\delta^{18}O$ speleothem records. Quat. Sci. Rev. 146, 274–287.

Cachão, M., 1990. Posicionamento biostratigráfico da jazida pliocénica de Carnide (Pombal). Gaia 2, 11–16.

Chahal, P., Kumar, A., Sharma, C.P., Singhal, S., Sundriyal, Y.P., Srivastava, P., 2019. Late Pleistocene history of aggradation and incision, provenance and channel connectivity of the Zanskar River, NW Himalaya. Global and Planetary Change 178, 110–128.

Clark, M.K., Schoenbohm, L.M., Royden, L.H., Whipple, K.X., Burchfiel, B.C., Zhang, X., Tang, W., Wang, E., Chen, L., 2004. Surface uplift, tectonics, and erosion of eastern Tibet from large-scale drainage patterns. Tectonics 23, TC1006. doi:10.1029/2002TC001402

Cunha, P.P., 2019. Cenozoic Basins of Western Iberia: Mondego, Lower Tejo and Alvalade basins. In: The Geology of Iberia: A Geodynamic Approach (Quesada, C., Oliveira, J.T., Eds.), Regional Geology Reviews, Springer International Publishing, Vol. 4 – Cenozoic Basins, Chapter 4, pp. 105–130. DOI: 10.1007/978-3-030-11190-8

Cunha, P.P., Martins, A.A., Buylaert, J.-P., Murray, A.S., Raposo, L., Mozzi, P., Stokes, M., 2017. New data on the chronology of the Vale do Forno sedimentary sequence (Lower Tejo River terrace staircase) and its relevance as fluvial archive of the Middle Pleistocene in western Iberia. Quat. Sci. Rev. 166, 204–226.

Cunha, P.P, Martins, A.A., Gomes, A., Stokes, M., Cabral, J., Lopes, F.C., Pereira, D., de Vicente, G., Buylaert, J.-P., Murray, A.S., Antón, L., 2019. Mechanisms and age estimates of continental-scale endorheic to exorheic drainage transition: Douro River, Western Iberia. Global and Planetary Change 181, doi.org/10.1016/j.gloplacha.2019.102985

Demir, T., Westaway, R., Bridgland, D., 2018. The influence of crustal properties on patterns of Quaternary fluvial stratigraphy in Eurasia. Quaternary 1, 28 doi:10.3390/quat1030028

Gouveia, M.P., Cunha, P.P., Falguères, C., Voinchet, P., Martins, A.A., Bahain, J.-J., Pereira, A., 2020. Electron spin resonance dating of the culminant allostratigraphic unit of the Mondego and Lower Tejo Cenozoic basins (W Iberia), which predates fluvial incision into the basin-fill sediments. Global and Planetary Change 184, doi.org/10.1016/j.gloplacha.2019.103081

Hintersberger, E., Thiede, R.C., Strecker, M.R., Hacker, B.R., 2010. East–west extension in the NW Indian Himalaya. Geological Society of America Bulletin 122, 1499–1515.

Hu, X., Wen, Z., Pan, B., Guo, L., Cao, X., 2019. Constraints on deformation kinematics across the Yumu Shan, NE Tibetan Plateau, based on fluvial terraces. Global and Planetary Change 182, doi.org/10.1016/j.gloplacha.2019.103023

Hu, Z., Wang, X., Pan, B., Bridgland, D.R., Vandenberghe, J., 2017. The Quaternary of the Upper Yellow River and its environs: Field Guide. Quaternary Research Association, London.

Hu, Z., Li, M., Dong, Z., Guoc, L., Bridgland, D., Pan, B., Li, X., Liu, X., 2019. Fluvial entrenchment and integration of the Sanmen Gorge, the Lower Yellow River. Global and Planetary Change 178, 129–138.

Kanner, L.C., Burns, S.J., Cheng, H., Edwards, R.L., Vuille, M., 2013. High-resolution variability of the South American summer monsoon over the last seven millennia: insights from a speleothem record from the central Peruvian Andes. Quat. Sci. Rev. 75, 1–10.

Li, J., Fang, X.M., Pan, B., Zhao, Z., Song, Y., 2001. Late Cenozoic intensive uplift of Qinghai–Xizang Plateau and its impacts on environments in surrounding area. Quaternary Science 21, 381–391.

Lin, A., Yang, Z., Sun, Z., Yang, T., 2001. How and when did the Yellow River develop its square bend? Geology 29, 951–954.

Liu, S., Zhang, G., Pan, F., Zhang, H., Wang, P., Wang, K., Wang, Y., 2013. Timing of Xunhua and Guide basin development and growth of the northeastern Tibetan Plateau, China. Basin Research 25, 74–96.

Molnar, P., England, P., Martinod, J., 1993. Mantle dynamics, uplift of Tibetan Plateau, and the Indian Monsoon. Reviews of Geophysics 31, 357–396.

Molnar, P., Tapponnier, P., 1975. Cenozoic tectonics of Asia: effects of a continental collision. Science 89, 419–426.

Peltzer, G., Tapponnier, P., 1988. Formation and evolution of strike-slip faults, rifts, and basins during the India-Asia collision: an experimental approach. Journal of Geophysical Research 93, 15085–15117.

Peng, F., Prins, M.A., Kasse, C., Cohen, K.M., Van der Putten, N., van der Lubbe, J., Toonen, W.H.J., van Balen, R.T., 2019. An improved method for paleoflood reconstruction and flooding phase identification, applied to the Meuse River in the Netherlands. Global and Planetary Change 177, 213–224.

Perrineau, A. Van der Woerd, J., Gaudemer, Y., Jing Liu-Zeng, Pik, R., Tapponnier, P., Thuizat, R., Zheng Rongzhang, 2011. Incision rate of the Yellow River in Northeastern Tibet constrained by ^{10}Be and ^{26}Al cosmogenic isotope dating of fluvial terraces: implications for catchment evolution and plateau building. Geological Society, London, Special Publication No. 353, pp. 189–219.

Ramos, A., Cunha, P.P., Cunha, L., Gomes, A., Lopes, F.C, Buylaert, J.-P., Murray, A.S., 2012. The River Mondego terraces at the Figueira da Foz coastal area (western central Portugal): geomorphological and sedimentological characterization of a terrace staircase affected by differential uplift and glacio-eustasy. Geomorphology 165–166, 107–123.

Stansell, N.D., Rodbell, D.T., Abbott, M.B., Mark, B.G., 2013. Proglacial lake sediment records of Holocene climate change in the western Cordillera of Peru. Quat. Sci. Rev. 70, 1–14.

Su, H., Dong, M., Hu, Z., 2019., Late Miocene birth of the Middle Jinsha River revealed by the fluvial incision rate. Global and Planetary Change 183, doi.org/10.1016/j.gloplacha.2019.103002

Tapponnier, P., Xu, Z.Q., Roger, F., Meyer, B., Arnaud, N., Wittlinger, G., Yang, J.S., 2001. Oblique stepwise rise and growth of the Tibet Plateau. Science 294, 1671–1677.

Viveen, W., Zevallos-Valdivia, L., Sanjurjo-Sanchez, J., 2019. The influence of centennial-scale variations in the South American summer monsoon and base-level fall on Holocene fluvial systems in the Peruvian Andes. Global and Planetary Change 176, 1–22.

Vuille, M., Burns, S.J., Taylor, B.E., Cruz, F.W., Bird, B.W., Abbott, M.B., Kanner, L.C., Cheng, H., Novello, V.F., 2012. A review of the south American monsoon history as recorded in stable isotopic proxies over the past two millennia. Clim. Past 8, 1309–1321.

Wang, J., Hu, Z., Pan, B., Li, M., Dong, Z., Li, Xiaohua, Li, Xiaoqiang, Bridgland, D., 2019. Spatial distribution pattern of channel steepness index as evidence for differential rock uplift along the eastern Altun Shan on the northern Tibetan Plateau. Global and Planetary Change 181, doi.org/10.1016/j.gloplacha.2019.102979

Wang, Y., Xu, Q., Li, D., Han, J., Lü, M., Wang, Y., Li, W., Wang, H., 2011. Late Miocene Red River submarine fan, northwestern South China Sea. Chin. Sci. Bull. 56, 1488–1494.

Wu, D., Li, B., Lu, H., Zhao, J., Zheng, X., Li, Y., 2019. Spatial variations of river incision rate in the northern Chinese Tian Shan range derived from late Quaternary fluvial terraces. Global and Planetary Change185, doi.org/10.1016/j.gloplacha.2019.103082

Xu, Y., Lai, Z., Li, C., 2019. Sea-level change as the driver for lake formation in the Yangtze Plain – A review. Global and Planetary Change 181, doi.org/10.1016/j.gloplacha.2019.102980

Yang, X., Wanga, X., Van Balen, R.T., Prins, M.A., Wang, S., van Buuren, U., Lu, H., 2019. Fluvial terrace formation and its impacts on early human settlement in the Hanzhong basin, Qinling Mountains, central China. Global and Planetary Change 178, 1–14.

Zhang, W., Yan, M., Fang, X., Zhang, D., Zhang, T., Zan, J., Song, C., 2019. High-resolution paleomagnetic constraint on the oldest hominoid-fossil-bearing sequence in the Xiaolongtan Basin, southeast margin of the Tibetan Plateau and its geologic implications. Global and Planetary Change 182, doi.org/10.1016/j.gloplacha.2019.103001

Zhang, Y., Ma, Y., Yang, N., Shi, W., Dong, S., 2003. Cenozoic extensional stress evolution in North China. Journal of Geodynamics 36, 591–613.

David R. Bridgland[a], Zhenbo Hu[b], Jef Vandenberghe[c], Xianyan Wang[d]

[a]Department of Geography, Durham University, South Road, Durham DH1 3LE, UK

[b]Key Laboratory of Western China's Environmental Systems (Ministry of Education), College of Earth and Environmental Sciences, Lanzhou University, Lanzhou 730000, People's Republic of China

[c]Department of Earth Sciences, VU University, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands

[d]School of Geographic and Oceanographic Sciences, the MOE Key Laboratory of Coast and Island Development, Nanjing University, Nanjing 210093, People's Republic of China

E-mail address: d.r.bridgland@durham.ac.uk (D.R Bridgland).